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Inefficiencies caused by non-harmonized capacity mechanisms in an interconnected electricity market

H. Höschle [a,b,c,*], H. Le Cadre [a,c], R. Belmans [a,b]

[a] EnergyVille, Thorpark 8310, 3600 Genk, Belgium
[b] KU Leuven, Electa, Kasteelpark Arenberg 10, 3001 Leuven, Belgium
[c] VITO, Boeretang 200, 2400 Mol, Belgium

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ABSTRACT

The European Internal Energy Market consists of many interconnected market zones. Unless transmission capacities are constrained, these market zones share capacity assets and injected energy to the benefit of the system. Market and price coupling allows making use of resources more efficiently. These efficiency gains are grounded on the harmonization of system operation and market rules. However, various capacity mechanisms (CMs) are put in place on national level that undermine the process of harmonization and complicate efficient market coupling. This paper addresses the inefficiencies caused by non-harmonized CMs. We propose a novel model formulation including generators, a market operator, an interconnection operator and an aggregated set of consumers. The model combines market clearings with investment decision in generation and transmission. The formulation allows for multiple market zones with different CMs. The model is set up as non-cooperative game whose properties are analyzed through the computation of a Nash Equilibrium. The model quantifies average cost, energy not served, and reserve margins per zone and system. The changing net exchange between markets and installed capacities are evaluated. A case study with three zones highlight the inefficiencies of wrongly estimating the contribution from neighboring market zones. These can be reduced by a shared assessment of capacity demands in coupled CMs and cross-border participation. A sensitivity analysis distinguishes explicit and implicit cross-border contributions. The results suggest that a common approach to CMs yields beneficial outcomes from a regional perspective. However, wrong estimation (under or over) of cross-border participation leads to different economic inefficiencies.

1. Introduction

This paper addresses the current discussion about the implementation and harmonization of capacity mechanisms (CMs) in EU Member States. In order to quantify the inefficiencies that result from non-harmonized CMs, we highlight important market parameters that affect the efficiency of CM harmonization and cross-border participation.

1.1. Internal energy market and capacity mechanisms

The European Internal Energy Market (IEM) consists of many interconnected market zones. Unless transmission capacities are constrained, these market zones share capacity assets and injected energy to the benefit of the system. The overarching target set by the European Commission for the IEM [1] is to create an adequately interconnected, market-based energy system. Market signals should create incentives for necessary investments into generation and transmission. Such a market would yield the economically most effective outcome and minimize the need for state-planned investments.

However, there are doubts about the capability of the current market to attract adequate investments to ensure the current level of security of supply. The European Commission [1] acknowledges that shortcomings of the current market arrangements reduce the attractiveness for new investments.

CMs are considered in many EU Member States as a means to address national concerns about generation adequacy. Market frameworks are redesigned accordingly [2]. CMs can take various forms, such as direct capacity payments, market-wide capacity markets, reliability options, or targeted strategic reserves. Their varying working principles, participation rules and impact on the market outcome have been discussed and analyzed. An overview of currently implemented CMs can be found for example in [3]. A recent survey shows that many markets worldwide implement CMs for different reason including lack of interconnection, increased

* Corresponding author at: EnergyVille, Thorpark 8310, 3600 Genk, Belgium.
E-mail address: hanspeter.hoschle@energyville.be (H. Höschle).

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shares of Renewable Energy Sources (RES), or seasonal demand fluctuations [4].

However, in the context of the European IEM, non-harmonized CMs in the interconnected energy system is an additional threat for the efficiency of the market operation. According to [5], different degrees of harmonization are possible. However, national market redesigns seem to aim at national generation adequacy rather than seeking a wider regional coordination. The resulting patchwork of different CMs undermines the harmonization process. The European Commission [1] clearly states that if implemented, CMs should be designed to minimize distortions to the IEM.

In a setting with CMs, the participation in the CM of capacity suppliers from neighboring markets, i.e., cross-border participation, is promoted to increase efficiency. Following the European Commission [6], cross-border participation ensures incentives for continued investment in interconnection and reduces the long-term costs of security of supply. However, the efficiency depends on how remunerations are affected and the decision-making of market participants changed accordingly. Variations in remuneration of assets in the individual markets could lead to welfare losses [7].

1.2. Cross-border participation in capacity mechanisms

Assuming that the decision for or against a CM was taken based on clearly identified needs, cross-border participation is a means to make best use of assets in neighboring markets that contribute to generation adequacy. For that reason, the European Commission [8] argues that generation adequacy assessments need to take into account interconnection capacity and non-domestic generation capacity.

In the literature and in current implementations different forms of cross-border participation can be identified:

- No participation: Non-domestic capacity cannot participate because flows during scarcity are assumed unreliable, e.g., in Spanish, Portuguese capacity payments [6];
- Implicit participation: Non-domestic capacity is deducted from the capacity demand or implicitly accounted for as zero bids, e.g., Italian reliability options [6], Belgian strategic reserves (SR) [9];
- Explicit participation: Non-domestic capacity or interconnectors directly participate and compete with domestic supply. Participation is limited by the de-rating of generation and/or interconnection capacity, e.g., interconnector participation in Great Britain (GB) capacity market [10].

While implicit participation is considered easier to implement because of its estimation during capacity demand assessments, explicit participation and the associated de-rating of capacity might be challenging [11]. The de-rating of capacity is linked to the question of ensuring delivery during scarcity events and the possibility to participate in multiple CMs in neighboring markets. In order to limit the necessary assessments to few interconnection capacities, the interconnector model is preferred by multiple studies. The delivery is easier to follow and the approach offers a direct investment signal for interconnection capacity [12,13]. These capacity-based price signals for interconnection improves their economic efficiency [7].

Alternatively, a generator model, i.e., participation of non-domestic capacity, would require an additional auctioning of transmission capacity in either an implicit or an explicit form comparable to practice for energy markets. This could indirectly also provide an investment signal for interconnection capacity.

Several recent studies [14–16] show that the harmonization of the CMs itself, combined with cross-border participation across multiple markets, is beneficial. Non-harmonized implementations of CMs could reduce economic efficiency and even negatively affect the security of supply. Moreover, the implementation of a CM in one market may cause pressure on neighboring countries to implement a CM as well [15]. In addition to harmonization, [16] highlight that a regional capacity assessment and sound de-rating is crucial for the efficiency.

As a goal for harmonization, one could target a fully harmonized and coupled market-based CM with cross-border participation of de-rated generation, load, or storage. The cross-border participation would be determined based on capacity price differentials similar to the energy market. The resulting congestion rents provide a market-based signal for interconnection investment, similar to the interconnector model.

1.3. Models for interconnected capacity mechanisms

Different approaches for the assessment of the effects of non-harmonized CMs and cross-border participation can be found in the literature. For example, large-scale system cost minimization models are used [11,16]. These models focus on potential cross-border participation via probabilities of contribution to security of supply but they do not differentiate between different CMs. [15] proposes an agent-based model with expert-rules to judge investment based on net present value (NPV) in a setting with interconnected SR and capacity markets. However, no cross-border participation is included. [14,17] apply stylized analytical equilibrium models. These models are limited in the representation of operational details and RES participation. Based on a load duration curve, their models quantify price, capacity and welfare effects.

An equilibrium model with hourly operational details and representation of different CMs is proposed in [18]. Market participants are modeled as individual agents that take investment and operational decisions under the assumption of perfect competition. The model is extended in [19] to two symmetrical interconnected market zones. Its focus is to analyze the impact of increasing interconnection capacity on generation adequacy with different combinations of CMs. However, the model does not account for cross-border participation and only provides results in a symmetrical case. In this paper, we formulate an extension to that model which allows for more far-reaching studies.

1.4. Contributions

The contribution of the paper is threefold. First, we propose a novel model formulation to represent a market setting of interconnected market zones that may implement different CMs. In particular, this can be in form of SR or a capacity market. Hereby, the model is not limited in the number of market zones or configuration of the CMs. In comparison to similar model approaches, the proposed model combines hourly temporal resolutions for operational details with investment in generation and transmission. Additionally, the modeling approach incorporates the possibility to study cross-border participation in CMs, which is assumed either to be implicit or explicit.

Second, we apply game theory to the proposed model formulation and set up a non-cooperative game. Each market participant acts independently and simultaneously. It selfishly maximizes its own utility, e.g. profits or surplus. We apply the solution concept of Nash Equilibrium (NE) and use the obtained equilibrium for the economic interpretation of different market settings. We apply the proposed model in a case study with three markets including different scenarios. The scenarios differ in the choice of CMs and the incorporation of cross-border contribution.

Finally, the obtained equilibria are compared based on indicators derived from the installed capacities, market prices and market volumes. We use the results for an economic analysis.